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Drought Estimation in Southern Forest Fire Control

by

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INTRODUCTION

A simple method for gaging the intensity of drought would be valuable to men responsible for fire control in the South. They want to know when soil moisture becomes reduced to a level where fire-control difficulties are intensified--as for instance, when fires creep under lines in buried material and rekindle outside. They want to know whether normally wet areas such as branch heads and bays have become so dry that fire will sweep through the heavy fuels with increased intensity instead of being stopped, and whether fires will easily spot over plowed lines.

During extended droughts, aerial fuels become more flammable, firelines are hard to build and hard to hold, fires burn with great intensity and high rate of spread, and sometimes high-intensity fires produce convection columns that spew firebrands for long distances. As examples of what can happen during prolonged periods of little rain, in 1955 and 1956 four fires in the South each burned more than 100,000 acres. Drought conditions coupled with certain atmospheric conditions caused this excessive loss.

Type 8 and type 8-100 fire danger meters (7, 15), now in almost universal use in the East and South, were not designed to measure the deep drying of soils during droughts. To be sure, fuel moisture sticks used in connection with the meters are reliable indicators of the dryness of the thin upper layer of fuel, which is usually the first to ignite. And the Buildup Index is a measure of the moisture content of the 3 or 4 inches of fuel below the top layer. But neither of these indicators reflects soil moisture depletion during prolonged hot and rainless periods. For this reason, an attempt has been made to develop a measure of drought severity that can be used as a supplement to our present method of estimating fire danger.

This paper describes a possible approach to a system for estimating drought. It is based on the idea suggested by Thornthwaite (22) and others that the amount of water available to root systems of plants can be considered as a bank balance. Deposits to the bank are in the form of precipitation, and withdrawals in the combined form of evaporation and transpiration.

In developing the approach later described, it was necessary to consider a number of factors that might influence the rate and amount of bank deposits and withdrawals. These included the elements of weather that cause different types of forest stands to transpire at a fast or slow rate, root distribution, depth of soil profiles, water-holding capacity in soils of different texture, availability of soil moisture to root systems, and the effect of interception by tree foliage and stems on the amount of precipitation entering the soil. These factors are discussed in the first part of the paper so that the reader can better follow the reasoning that led to the development of the proposed drought indicator.

The method suggested is intended primarily for relatively flat terrain and for relatively deep inorganic soils where root development is not impeded by more or less impervious layers. However, some of the assumptions in this paper regarding soil moisture depletion and accretion may apply equally well to other soils and other areas.

There is voluminous literature on soil moisture depletion, droughts, evapotranspiration, and related subjects. Only a few references that seem particularly pertinent will be cited in this article. Lull (9) has excerpted a number of publications; and people interested in additional references will find many excellent articles in the 1955 U. S. Department of Agriculture Yearbook (23).

EVAPOTRANSPIRATION

Water loss from soils is a complex of soil, weather, and plant relations. A great deal of work has been done on the subject, but principally by those interested in the production of agricultural or orchard crops. Much less study has been made of water loss from soil covered with forest growth.

Although contradictory evidence can be found on almost every other point, it is generally agreed that water available to plants is lost from the soil largely through evaporation and transpiration. In a forest stand, transpiration is by far the most important. For the purpose of this report, both losses will be described by the commonly used term evapotranspiration and referred to as ET.

According to Thornthwaite and Hare (22), ET depends on:

1. Amount of energy supplied to the evaporating surface, principally by solar radiation

2. Removal of vapor from evaporating surface, as by wind

3. Type of vegetation and depth of root system

4. Nature of the soil and the amount of available water in the root zone

Many investigators subscribe to the concept advanced by Thornthwaite (21) that mean temperature can be used to measure ET if allowance is made for latitude, i.e., length of day. Other variables such as wind and relative humidity affect the rate of vapor removal from evaporating surfaces but apparently their effect, as well as length of day in the South, is not of sufficient magnitude to warrant inclusion in any simple estimating procedure. Therefore, in the present report, it is assumed that water available to forest stands is lost primarily through transpiration, and that the rate of loss can be estimated from mean temperature.

EFFECT OF SOIL MOISTURE CONTENT ON RATE OF TRANSPIRATION

Do forest stands--or for that matter, other types of vegetation--remove water from the soil at approximately the same rate regardless of the amount of available water? This question has an important bearing on the development of a method for estimating moisture depletion. The experts disagree.

On the one hand, Thornthwaite and Hare (22) state specifically, "...the evapotranspiration rate which diminishes as the soil dries is proportional to the water in the soil. When the soil moisture is reduced to 50 percent of capacity, the actual evapotranspiration rate will be only 50 percent of the potential rate." Taylor and Slater (20) say, "Although the plant roots take water freely from soils at field capacity, the work required to remove the water becomes progressively greater as the soil becomes drier and the forces of retention increase." According to Zahner (28), "Although there is some variation with soil type, for practical consideration it can be assumed that the rate of moisture depletion by upland pine-hardwood forests is directly proportional to the moisture content of the surface six feet of soil--the effective root zone."

On the other hand, Veihmeyer and Hendrickson (25), in writing about the irrigation of orchards, state "...soil moisture, from field capacity down to the permanent wilting percentage, is readily available to plants..." This view is supported by Wadleigh (26) "...there is evidence indicating that, for practical purposes, soil water is essentially equally available almost down to the wilting percentage." Hoover, Olson, and Greene (6) found that in an 11-year-old loblolly pine plantation in South Carolina, water was removed at a depth of 54 to 66 inches at about the same rate as from shallower depths. More recently, Fletcher and McDermott (3) report that on an Ozark Ridge soil, transpiration depleted soil moisture at a uniform rate until the supply was virtually exhausted.

Differences of opinion as to the effect that amount of soil moisture has on rate of transpiration probably arise in part from the fact that different investigators have used different plant materials, soils, and techniques of measurement. Furthermore, there seems to be no simple or certain method of measuring moisture in deep soil profiles. It is also worth mentioning that a number of investigators have considerable misgivings about some of the

transpiration rates found in literature. Stone (19), for example, states "...evaporation measured from isolated trees or portions thereof cannot be related, even theoretically, to losses from an area of forest vegetation nor can the results of conventional pot cultures."

Considering that no attempt is made to differentiate between soil types in this report, and that only an approximation of soil moisture is intended, it will be assumed in this paper that rate of moisture depletion is the same from field capacity to wilting range.

SOIL MOISTURE MEASUREMENT

Irrigationists, soil technicians, hydrologists, engineers, foresters, and many others are concerned with daily and periodic changes in soil moisture. Consequently, much attention has been given to devising measurement techniques. Brief mention of the methods most commonly used will be made here, mainly for the purpose of emphasizing that there is no easy, accurate, and inexpensive way of measuring soil moisture. This is particularly true of forest soils, where depth of profile is measured in feet rather than inches.

The simplest yet the most laborious and time-consuming method of measuring soil moisture is to weigh the fresh field sample, ovendry it to constant weight, reweigh it, and express the moisture content in percent of ovendry weight. If bulk density--the relation of the weight of the ovendry sample to its field volume--is known, moisture content can readily be converted to volume percent.

The main difficulty in this gravimetric method is in obtaining samples. Although a variety of soil tubes, augers, and mechanized core drillers have been developed, the necessary labor places a physical limitation on the number of samples that can be obtained in a day. This is a decided disadvantage where close watch of daily moisture is desired. Another disadvantage is that the same point cannot be resampled.

Lull and Reinhart (10) point out that for the gravimetric method, sampling conditions are ideal when the soil is just moist enough so that the sampling instrument can be easily inserted and withdrawn and where roots and stones are not a problem. They add that such conditions are rarely encountered.

To overcome difficulties inherent in gravimetric measurements, electrical units that can be left in place at any desired depth of soil have been developed. The units consist of electrodes variously embedded or contained in blocks of absorbent material, the commonest being plaster of paris, fiberglas, and nylon, or combinations of these. Presumably the moisture content of the absorbent material varies with that of the soil. The measured electrical resistance is an index of soil moisture when the blocks are calibrated for a particular soil.

The electrical-resistance method has certain advantages and disadvantages. A metering unit can easily be attached to terminals leading to blocks at different depths, and measurements made as often as desired without the labor of taking soil samples. However, Olson and Hoover (16), Lull and Reinhart (10), and Haise (4), among others, point out that there are many sources of error. For example, gypsum blocks lack durability; soil salinity can greatly modify measurements; compensation must be made for temperature; units must be carefully calibrated; units must be installed most carefully to avoid gross errors; some types of units are sensitive at certain moisture ranges but not at others; and units must be calibrated periodically against gravimetric determinations.

Two other methods have been used with more or less success. Tensiometers measure water in a soil by means of a porous cup filled with water and attached to the end of a tube inserted in the soil. Tension, and corresponding soil moisture, is determined by means of a vacuum gage or a mercury manometer. Such instruments have been used in estimating irrigation needs but apparently are not satisfactory where the full range of soil moisture is to be determined. Studies of methods for estimating soil moisture by measuring the scattering of neutrons with electronic instruments indicate that further improvements in techniques and instrumentation are needed.

As implied in the previous discussion, all methods of measuring soil moisture require expertness of methodology. There is no simple instrumental method that can be suggested for routine field use by fire control men. Furthermore, as stated by Lull and Reinhart (10), any sampling method gives results that are variable because moisture changes from day to day, point to point, and depth to depth. There can be large variations even within a relatively small area because of uneven wetting of the soil profile by rain, because of soil heterogeneity, uneven root distribution, and uneven surface conditions. To sum up, determination of drought conditions for general field use by fire control men must be by estimation rather than by direct measurement, at least for the present.

TYPE OF VEGETATION AND SOIL MOISTURE DEPLETION

There seems to be no doubt that different types of plants have different consumptive uses. Peak rates per day reported in the Yearbook of Agriculture (23) range from 0.25 to 0.50 inch. The question arises whether pine and hardwood stands differ materially in this respect. Theoretically, hardwoods should use less than pines because hardwood foliage has slightly higher reflectivity, but it is doubtful whether the small difference is significant. Some evidence on this point is available from work at the Southern Forest Experiment Station.

Moyle and Zahner (14) from studies of all-aged pine stands and hardwood stands at Crossett, Arkansas, concluded that soil depletion curves for a depth to 48 inches during a dry period in 1953 were almost identical. This was corroborated by Zahner (27), who reported in another study that the rates of soil

water depletion were approximately the same for pure pine and pure hardwood stands similar in climate, stocking, and site. Although the hardwood curve lagged about a week behind the pine, Zahner attributed this lag to greater water storage under the hardwood stand. He concluded that his results supported theories that evapotranspiration within a given climatic area is independent of the type of forest cover.

That the amount of vegetation on an area greatly influences the rate of transpiration is well known. For example, in one study of a hardwood stand at the Coweeta Hydrologic Laboratory, near Franklin, North Carolina, all the woody vegetation on a watershed was cut, with a resultant increase in streamflow amounting to 17 area inches the first year after cutting, and presumably a comparable reduction in transpiration. Moyle and Zahner (14) found that during hot dry weather in the summer of 1953 pine and hardwood stands with a stocking of 70 to 100 square feet of basal area on the Crossett Experimental Forest quickly depleted soil moisture. On plots where large cull hardwoods had been girdled or all living vegetation removed, soil moisture remained relatively high.

The method of calculating water losses through evapotranspiration suggested in this report is considered as applicable only to fairly well-stocked stands, regardless of type.

ROOT DISTRIBUTION AND SOIL MOISTURE DEPLETION

As has been pointed out, most of the water lost from soil under forest stands is by transpiration. It follows that the distribution of the root system, and particularly the depth from which it can draw water, to a large extent determines how much and how fast water is lost from soil.

Little information is available on the deep root systems of trees. This is understandable considering the difficulty involved in excavating and mapping even the roots of small trees. Furthermore, generalizations are unsafe because root development can be greatly modified by soil structure, amount of water and nutrients present, aeration, competition from roots, and many other factors. Nevertheless, the following citations provide evidence on the depth of pine root penetration.

Heyward (5) reports that a 250-year-old longleaf pine growing on deep sands in western Florida had a taproot extending downward more than 14 feet. Seedlings 10 to 30 inches tall had taproots from 3 to 9 feet long. Ashe (1) illustrates a loblolly pine stump in a moist but well-drained sandy loam with a taproot of 10 feet. He adds that taproots of this species seldom descend to depths of more than 4 or 5 feet. They are much shorter on compact clay soils and hardpan than on loose soils. McQuilkin (12) from a study of pitch pine and shortleaf pine on well-drained sandy soils in New Jersey, states that vertical roots after reaching depths of 3 to 4 feet grew much more slowly than lateral roots and practically ceased to grow at depths of 8 to 9 feet.

Investigators are in general agreement that most of a tree's feeding roots are found in the upper soil layers. Hoover and others (6) state that for this reason there has been a tendency to discount the amount of water withdrawn by roots from deeper depths. They believe, "...root concentration or abundance may not necessarily be a reliable guide to either the rate or amount of water removed from a given soil depth." They also observe that there is abundant root growth in the upper soil layers because conditions there are favorable and not because a large mass of roots is needed to extract water.

In addition to storage capacity by a soil of specific texture, the total depth of profile into which roots can penetrate determines the amount of water available to plants. Rock strata, hardpans, and other impediments to root penetration obviously limit root development.

Perhaps some misconceptions regarding the availability of soil moisture to plant roots are worth mentioning. One might suppose that the water table could contribute considerable moisture to a dry soil. However, according to Lutz and Chandler (11) and others, capillary movement from moist to dry soils is too slow to be of much use to plants. Apparently roots grow pretty much at random but branch profusely when they reach moist and well-aerated areas. Kramer (8) states that there is no evidence that roots actually grow from dry to moist soils.

THE RANGE OF AVAILABLE WATER

The amount of water available to plants differs according to the type of soil and depth of profile. By available water is meant the amount between field capacity and wilting point. Field capacity is usually considered to be the amount of water that is held against gravity in a given depth of soil after saturation. Water in excess of this amount is called gravitational water and usually drains off in a few days or hours depending on type of soil. Wilting point has been defined in several ways: (a) the moisture content of soil when leaves of plants become permanently wilted; (b) the lower limit of soil moisture available for growth but not the lower limit available for absorption; and (c) the moisture held by soil against a force of 15 atmospheres.

The range of so-called constants for soils of different textures is given in figure 1. It will be noted that clay soils can hold much more water per foot than sandy soils, but they also have a higher wilting point.

The Southern Forest Experiment Station at the Waterways Experiment Station at Vicksburg studied the water-holding capacity of 37 soils. Field capacities ranged from 32 percent by volume for sandy loams to 42 percent for the heaviest soils. Wilting points by volume were 10 percent for sandy and silt loams, 14 percent for loams, and 25 percent for clays. Available water for silt loams averaged 30 percent, loams 25 percent, sandy loams 22 percent, and clays 17 percent.

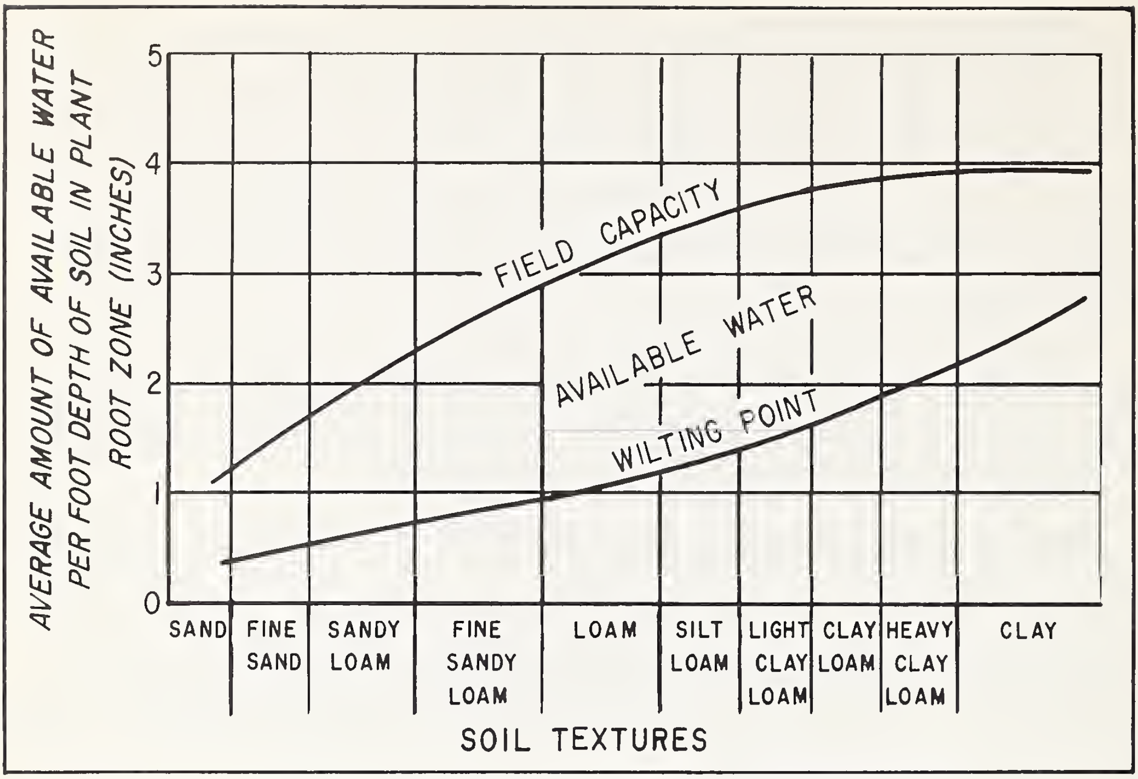

Figure 1.--Typical water holding characteristics of different-textured soils. (Adapted from 1955 U. S. Department of Agriculture Yearbook.)

According to Kramer (8) and many other investigators, plants can absorb water from soils drier than the wilting point, but absorption is too slow for diameter growth. Also, there is apparently little root growth in soils at or near the permanent wilting percent.

Reynolds (17) considers that forest soils in northern Louisiana and southern Arkansas can store from 8 to 14 inches of available water. This, he believes, is enough to allow for maximum growth of a well-stocked stand for 2 to 4 weeks without rainfall and for 4 to 7 weeks at some growth.

For purposes of illustration in later sections of this report, a 6-foot forest soil depth with a water-holding capacity of 2 inches per foot has been selected.

SOIL MOISTURE ACCRETION

The amount of water that actually enters the ground during or after a rain depends on many factors. Among these are amount, duration, and intensity of rainfall, amount of water present in the soil, type of soil, infiltration capacity, kind and depth of protective mantle, slope, and ground cover. Even if the individual or collective effects of these variables on accretion were known, it would not be possible to include them in any simple system of estimating soil moisture such as is proposed.

Much has been written about interception of precipitation by tree crowns and other forms of vegetation. Hoover and others (6) report that, on the average, in the pine plantation under observation, rainfall reaching the ground was 86 percent of that in the open. A large proportion of light rains but only a remarkably small percent of water by heavy rains was held by interception. They suggest that for pine stands the importance of interception may have been overemphasized. Thornthwaite and Hare (22), and Russell (18) (cited by Lull) state that energy used in evaporating intercepted water cannot be used in transpiration and therefore there may be no actual loss. In view of this concept, and in the interest of simplicity, interception as a factor in calculating accretion is ignored.

As was pointed out earlier, capillary water apparently does not move rapidly either upward, downward, or sideways. Kramer (8) states that if the water table is only a few feet below the surface, little upward movement occurs. This no doubt explains in part why some deep-burning ground fires in coastal organic soils during drought periods are not completely extinguished except by a drenching rain or a rise in the water table sufficient to drown the fire.

If a flat soil is at or near field capacity, most or all precipitation must seek lower levels such as ponds, bays, or streams. Similarly, if precipitation is of a duration and intensity that is beyond the infiltration capacity of the soil, the excess runs off. Since this report is primarily concerned with the flatwoods, runoff as a factor in accretion has been ignored except as follows: If, for example, a hypothetical soil profile with a field capacity of 12 inches has a computed 11 inches of water, the amount of rain in excess of one inch is considered as gravitational water and does not enter into accretion calculations.

After assuming that all precipitation up to field capacity could be considered as a deposit to the soil moisture bank, the next step was to derive transpiration loss values. Before proceeding with a discussion of how this was done, it may be well to summarize some of the other major assumptions made so far in this paper.

1. Mean daily temperature is the simplest determinant of rate of evapotranspiration. In this report mean temperature is an average of the highest and lowest temperatures for the day.

2. The rate of moisture depletion is the same from field capacity to wilting range.

3. A 6-foot soil profile with a field capacity of 2 inches per foot is representative of many forest stands in the South.

4. Interception and runoff need not enter into the calcuation of available water.

DERIVATION OF EVAPOTRANSPIRATION VALUES

Because mean temperature is recognized generally as the principal determinant of evapotranspiration, it was necessary to arrive at a set of water-loss values for a range of mean temperatures. These will be referred to as ET's. Search for such values that could be applied to forest stands led to work of the Southern Forest Experiment Station at the Waterways Experiment Station, Vicksburg, Mississippi. One of its reports (24) contains a curve of potential evapotranspiration based on Thornthwaite's formula (21) and average season transition dates. The curve of evapotranspiration values and a superimposed curve of Vicksburg mean temperature normals (1921-1950) is reproduced in figure 2. From these curves, preliminary ET's were derived that were about 25 percent less than the final values in table 1.

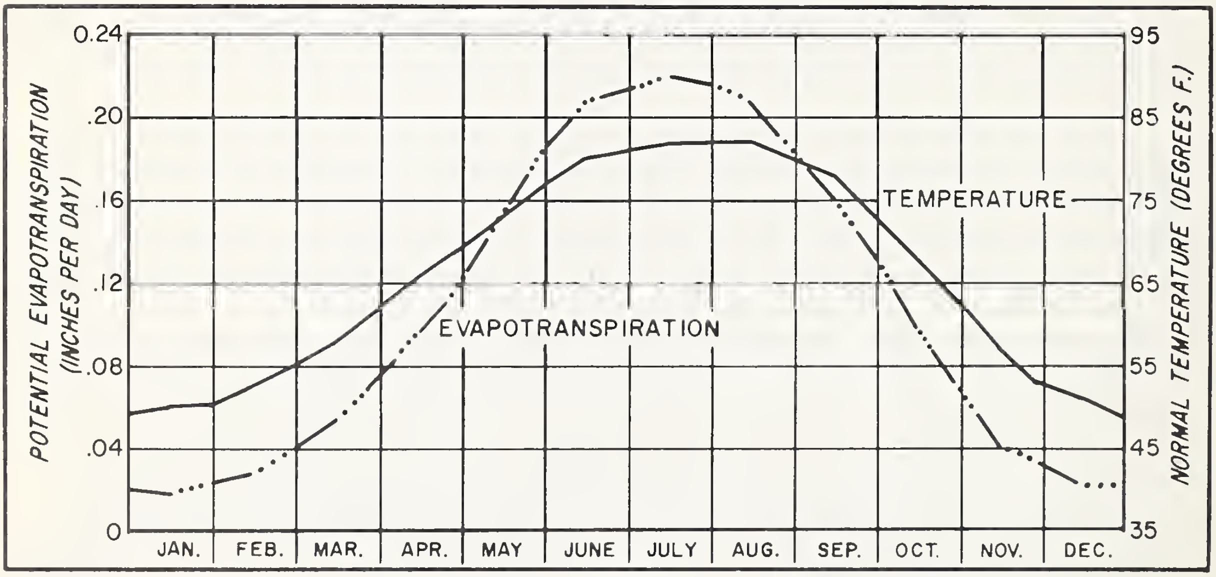

Figure 2.--Potential evapotranspiration values and normal temperatures for Vicksburg, Mississippi.

Table 1.--Estimated soil moisture loss according to daily mean temperature

Daily mean temp.	ET loss	Daily mean temp.	ET loss
Degrees F.	Inches	Degrees F.	Inches
50	.02	68	.13
51	.03	69	.14
52	.04	70	.14
53	.04	71	.15
54	.04	72	.16
55	.05	73	.17
56	.05	74	.18
57	.05	75	.19
58	.06	76	.20
59	.06	77	.21
60	.07	78	.23
61	.08	79	.24
62	.09	80	.25
63	.09	81	.26
64	.10	82	.27
65	.10	83	.28
66	.11	84	.30
67	.12	85	.32

Next, an approximation was attempted of the moisture depletion curve for the Crossett, Arkansas, untreated hardwood stand reported by Moyle and Zahner (14). Mean temperatures and rainfall for the period May 21 to July 14, 1953, were obtained from a report by Moyle (13) supplied by the Southern Forest Experiment Station. This period was selected because the soil was at field capacity at the beginning of the period and was later wetted by only small rains amounting to 1.12 inches. Using the preliminary ET's, subtractions from the soil moisture beginning on May 21 were made successively each day according to the mean temperature for that day. On days with rain the full amount of precipitation was counted as an accretion to the soil moisture. The measured depletion of available water in the hardwood site scaled from the curve in Moyle and Zahner's report (14), and my estimated depletion according to the just-mentioned procedure are given in figure 3. As will be seen, the rate of estimated depletion approximated the actual rate fairly well.

When a similar comparison was made using the all-aged Crossett pine stand depletion curve from Moyle and Zahner's report (14), and daily mean temperatures and precipitation reported for that site, a much poorer approximation was obtained (fig. 4). Because pine areas were of primary interest, a better set of ET values was sought by arbitrarily raising the preliminary values 25 percent (table 1).

These new ET's were used to estimate depletion for both the Crossett hardwood and pine sites (figures 5 and 6), with somewhat more satisfactory results, at least for the pine site. The ET's in table 1 were therefore used to derive illustrative depletion curves found later in this report.

It is apparent from the foregoing that the method used in deriving ET's has no very substantial basis, although there is some evidence that at higher mean temperatures the values may be reasonable. Zahner (28) estimated the water needs of forest stands in the mid-South for June, July, and August at about 8 inches per month. To compare my ET values against this figure, average monthly temperatures for 15 widely separated stations in the region were computed. They were found to be 79, 81, and 81 degrees respectively. Assuming a 31-day month, a mean temperature of 81 degrees, and an ET value of 0.26 from table 1, my estimated water loss is 8.1 inches. From another

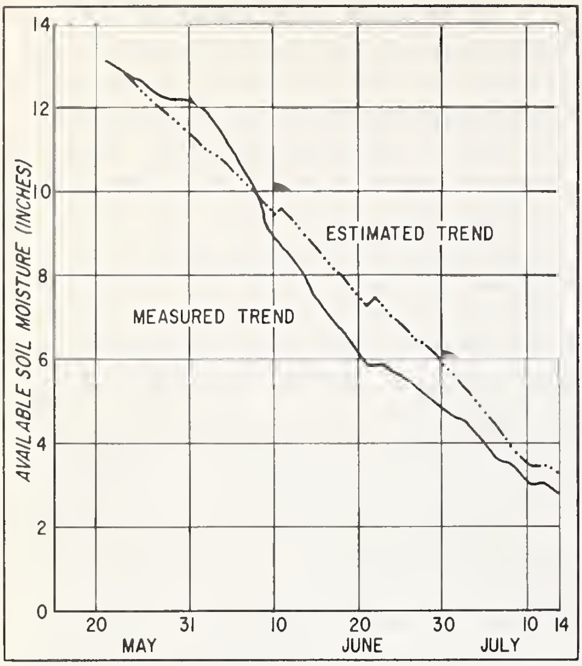

Figure 3.--Trend of available soil moisture in upper 48 inches on untreated hardwood site, Crossett, Arkansas, 1953 (adapted from Moyle and Zahner), and estimated depletion using preliminary ET's.

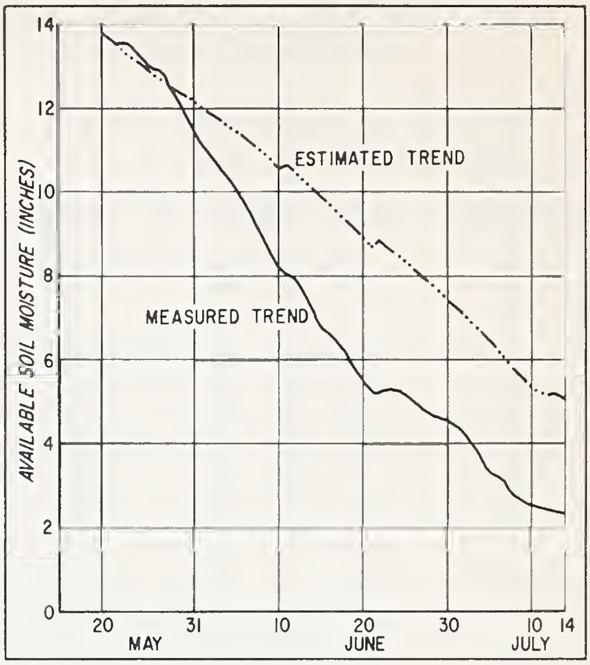

Figure 4.--Trend of available soil moisture in upper 48 inches on pine site, Crossett, Arkansas, 1953 (adapted from Moyle and Zahner), and estimated depletion using preliminary ET's.

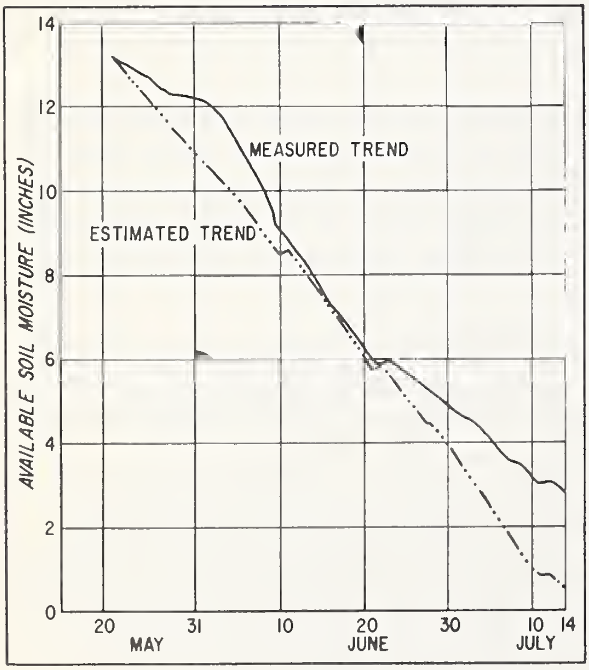

Figure 5.--Trend of available soil moisture in upper 48 inches on untreated hardwood site, Crossett, Arkansas, 1953 (adapted from Moyle and Zahner), and estimated depletion using ET values from table 1.

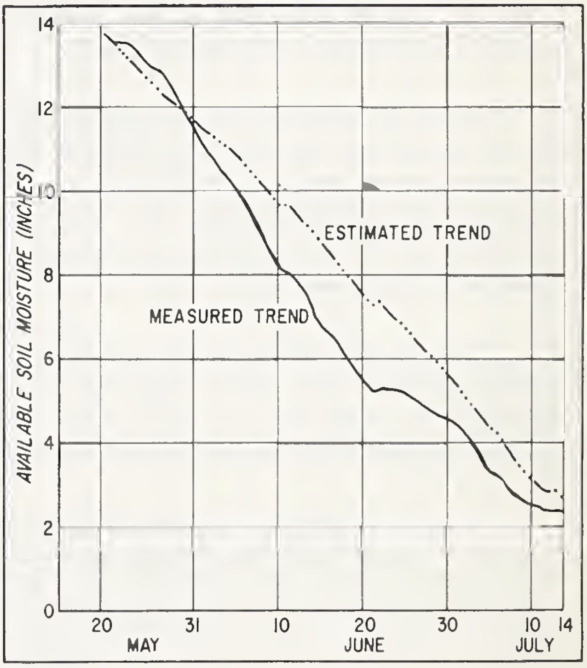

Figure 6.--Trend of available soil moisture in upper 48 inches on pine site, Crossett, Arkansas, 1953 (adapted from Moyle and Zahner), and estimated depletion using ET values from table 1.

study on the Crossett Experimental Forest, Zahner (27) estimated that for a 6-week period following June 2, 1954, the average soil moisture loss per day was about 0.25 inch in a 60-inch profile in both pine and hardwood stands. Using daily mean temperatures from Crossett Weather Bureau records for the same 6-week period and ET's from table 1, the writer calculated an estimated loss of 0.265 per day.

EXAMPLES OF ESTIMATED SOIL MOISTURE DEPLETION CURVES

During the course of the study reported in this paper a number of depletion curves were computed for Macon, Georgia, and District 2 in north Florida. Some of the curves are presented to illustrate the estimated march of soil moisture in drought and nondrought years.

Macon, Georgia, 1953-1954

Daily soil moisture values were computed for the Macon, Georgia, area beginning in April 1952. This month and year were selected as the starting point because the previous February and March had a total precipitation of 7.30 and 7.96 inches respectively. Field capacity for an assumed 6-foot profile almost certainly was reached during that period. Only values for 1953 and 1954 are plotted (fig. 7).

In examining these curves, the reader should remember that low moisture values in any particular month do not necessarily mean that a drought condition exists. For example, if soil moisture in the spring is at a low point, well scattered rains amounting to 8 or 9 inches in each of the summer months should supply ample moisture to upper soil layers for tree growth even though the soil profile as a whole may be relatively dry. It is the sharp decline in the curve, such as occurred in late May and part of June in 1953, and particularly the last half of May and all of June in 1954, that indicates the beginning of severe conditions. If such conditions are followed by weeks of low rainfall, then the drought becomes progressively worse.

The incipient drought in May and June of 1953 was followed by above-normal precipitation in July. This not only counterbalanced the heavy evapotranspiration draft but added somewhat to the water balance. Precipitation much above normal in late September, having again raised the level of soil moisture, partly offset the very low rainfall in October and November. For those months Macon Weather Bureau officials reported dry conditions, but apparently there was no critical shortage of soil moisture.

According to Weather Bureau data, rainfall in 1953 was nearly 12 inches above normal. This excess coupled with cooler than average temperatures brought about relatively moist conditions, as is suggested by the estimated depletion curve for that year.

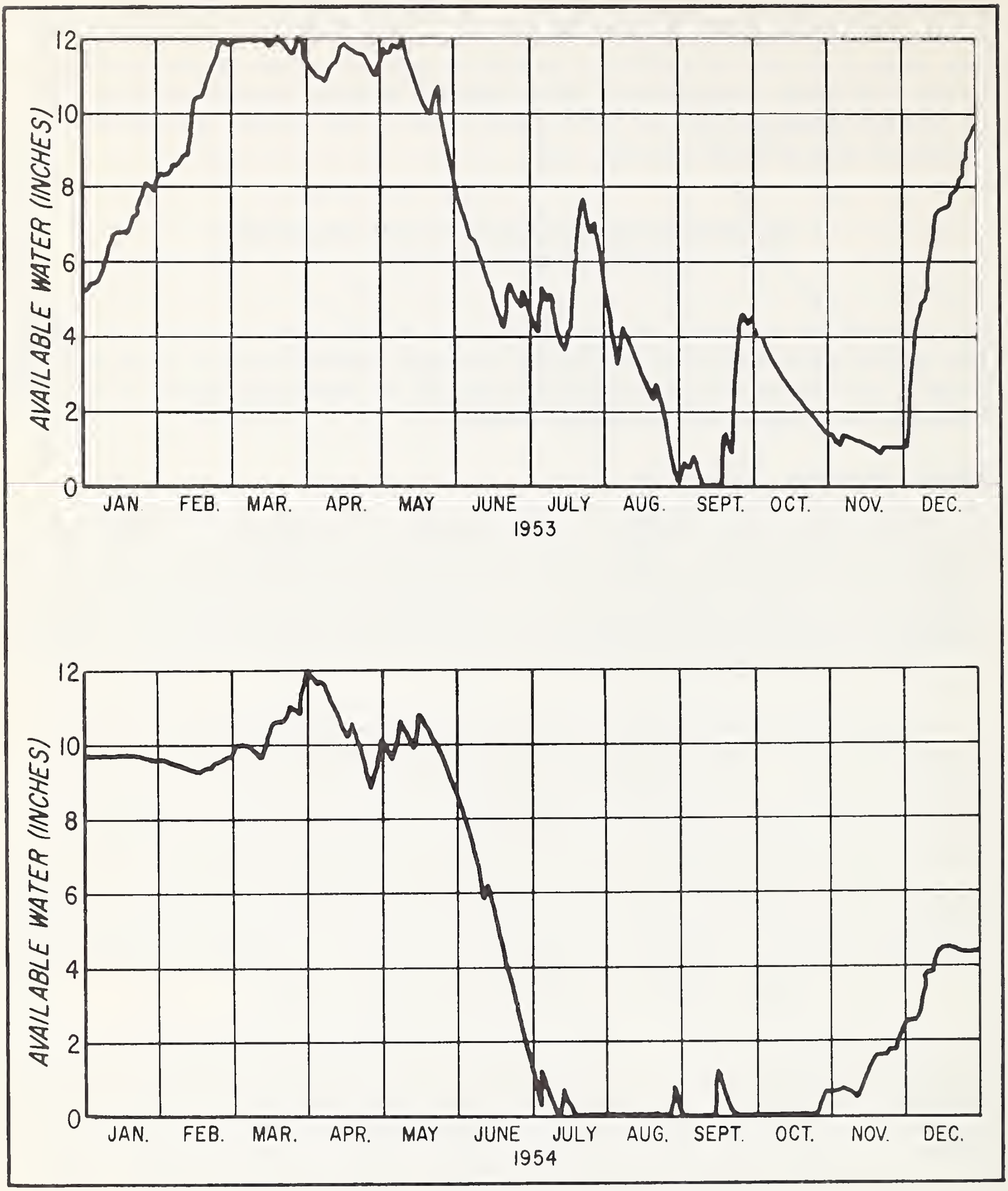

Figure 7.--Estimated soil moisture depletion, area of Macon, Georgia, 1953-1954.

The depletion curve for the last 6 months of 1954 presents a different picture. From all accounts it was one of the driest years on record. Total precipitation was only 56 percent of normal, and there was a deficiency in every month but November. Even so, during January, February, and March--which are months of low evapotranspiration--soil moisture remained high. It also remained high through April and the first half of May. After that, above-normal temperature and below-normal precipitation rapidly reduced soil moisture. During most of July, August, September, and October, soil to an assumed depth of 6 feet must have been at or near the wilting point.

The summer drought in mid-Georgia caused much damage to both crops and forests. Macon Weather Bureau officials reported that in June all growing crops had been damaged, in July the drought had reached major proportions, and in September practically all crops had been damaged beyond recovery, and that water sources were drying up. Brender and Hodges (2) estimated that the average loss of merchantable-size pines from mortality resulting from the 1954 drought in mid-Georgia was equivalent to one-half the normal growth in basal area, and that diameter growth of survivors was reduced by one-half. Death of seedlings and saplings caused additional losses.

Pine stands apparently are able to endure a surprising amount of dry weather. Hoover and others (6) found that during the severe drought in 1951 in the vicinity of Union, S. C., soil to a depth of 66 inches was at its wilting point for most of August. Though tube samples indicated no available water in the upper 96 inches of soil, no signs of wilting or unusual needle drop was observed.

Summer droughts in the South probably occur more frequently than is generally recognized. Moyle and Zahner (14) state, "During the summer, droughts occur nearly every year throughout the western portion of the shortleaf-loblolly pine-hardwood type, and lack of moisture undoubtedly limits tree growth." The same is probably true of a large part of the South.

District 2, Florida, 1953-1957

Depletion curves were computed for District 2 in north Florida for a period that included several extremely severe drought years. The District is a fire protection unit of the Florida Forest Service comprising 10 counties and bounded on the west by the Appalachicola River and on the east by the Suwanee River. Daily precipitation figures were obtained by averaging U. S. Weather Bureau records from 10 stations well scattered in the District. Mean temperatures for Tallahassee only were used, on the assumption that the city's central location provided reasonably good average figures for the area. Daily soil moistures were calculated, but for convenience semimonthly values only are plotted in figure 8.

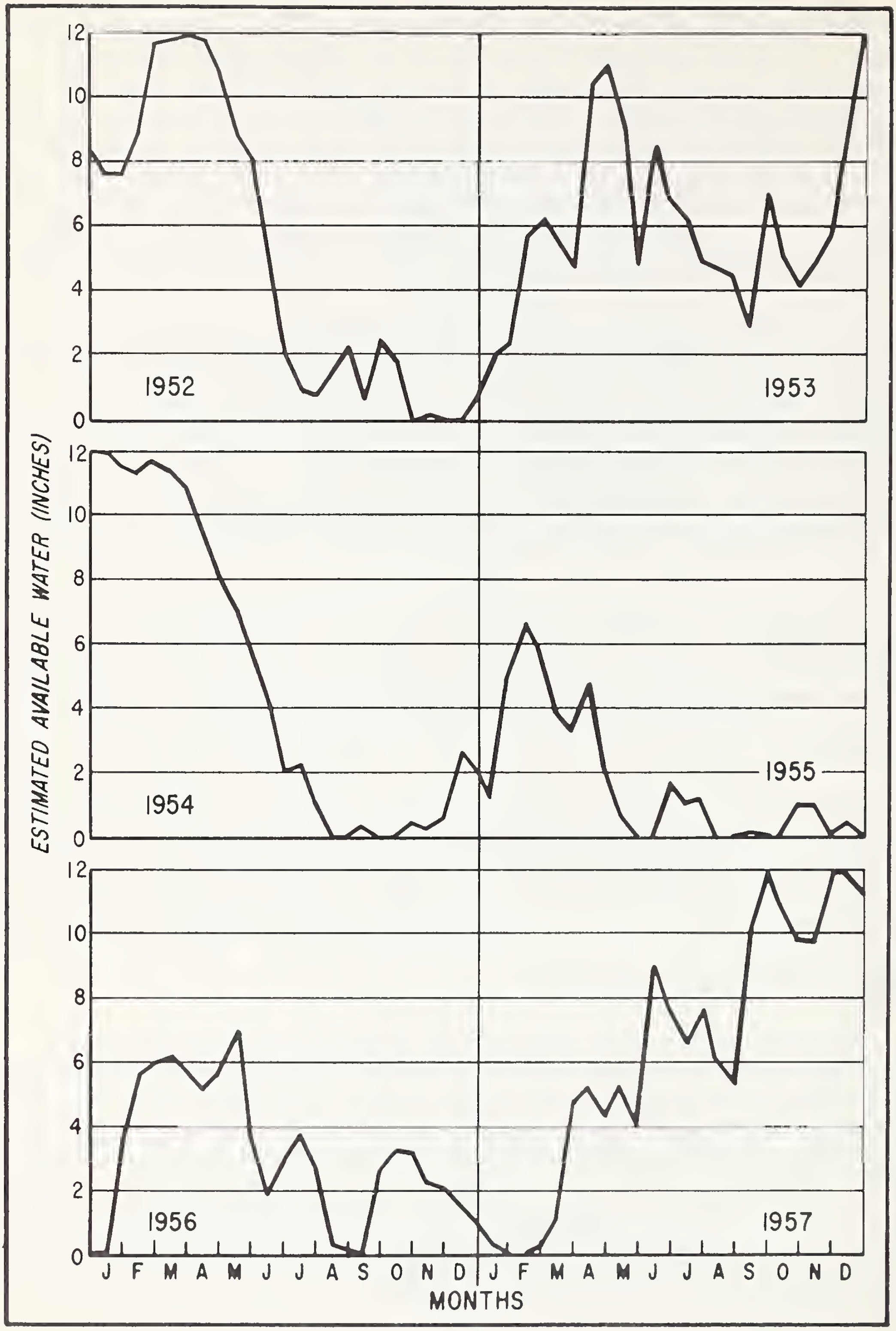

Figure 8.--Estimated soil moisture depletion curves, District 2, north Florida.

The main purpose of this series of soil moisture estimations was to determine whether definite relations between moisture depletion and fire history in the area for different years could be established. Accordingly, monthly records on number of fires, acres burned, and total acres protected were obtained from the Florida Forest Service. Analysis showed no clear-cut relation between number of fires and acres burned per million acres protected. Neither was average size of fire well related to trends in the depletion curves. This lack of relation was not entirely unexpected because certainly a great many factors other than soil moisture influence fire occurrence and behavior. For example, frequent light rains during a fire season may add little to the soil-moisture bank but may wet fuels enough so that fires do not easily start or spread. Acres burned and average size of fire as related to soil-moisture conditions can also be misleading because a single conflagration may exceed the total acreage burned in a protection unit even in a severe year.

Number of fires and acres burned per million acres protected in 1957 were decidedly lower than for any other year in the period. The next lowest year was 1953. The largest number of fires occurred in 1954, but 1955 was far in advance of other years in acres burned. These comparisons may not have much significance, since they do not take into account such factors as total Burning Index, adverse atmospheric conditions, manpower or machine efficiency, effectiveness of prevention, or increased funds available for fire protection.

According to observers, 1954 and 1955 were extremely difficult from a fire suppression standpoint in District 2 because of severe drought conditions. One State fire control official stated that from about August 1954 to the middle of June 1955, dry conditions made fire control almost impossible, particularly in swamps where muck and peat burned fiercely. A National Forest official reported that fires were very difficult to control in 1954, but in 1955 the situation became critical because of lack of soil moisture. There was some relief in 1956, but ponds and bays still remained relatively dry. Depletion curves for 1954, 1955, and 1956 appear to be in keeping with the foregoing reports.

APPLICATION

Following are suggestions to fire control men who think that some numerical measure of soil moisture conditions would be helpful and who are interested in testing the preliminary method described in this report:

1. Select one or more forest stations from which reliable daily precipitation and maximum and minimum temperature records are available.

2. From test borings, soil pits, or other sources of information in the general area of the station, estimate the depth of soil profile into which tree roots are able to penetrate.

3. Assume available water to be 2 inches per foot of profile depth, except for very sandy soils and unless specific information on this point can be obtained.

4. Select a starting date in the winter or spring when soil is at field capacity; that is, when there has been enough precipitation to wet the root zone thoroughly. An indicator of this condition is standing water for a few hours or days. Depth of saturation can be checked by test borings.

5. From the assumed number of inches of available water, make daily subtractions of estimated evapotranspiration according to mean temperatures and the ET values in table 1; on days with rain add the amount of precipitation minus the ET value for the day to the water balance but not to exceed the original inches of water. A sample form and graph are given in figures 9 and 10.

6. During periods of low rainfall, observe trends in the depletion curve and note at what points fire suppression becomes progressively more difficult <u>because of a lowering of soil moisture</u>.

7. From a series of such observations develop supplemental guidelines for fire control action during drought periods.

SOIL MOISTURE DAILY RECORD

Station ________________ Month _________ Year 19 __ Observer ________________

Day	Maximum Temperature	Minimum Temperature	Max. + Min. Temperature	Mean Temperature	ET	Rain	Estimated Soil Moisture	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
	---Degrees Fahrenheit---				Hundredths inches		Inches	
1	--	--	--	--	--	--	12.00	
2	82	58	140	70	14	--	11.86	
3	89	53	142	71	15	--	11.71	
4	85	63	148	74	18	--	11.53	
5	81	60	141	71	15	222	12.00	
6	73	47	120	60	7	--	11.93	
7	79	45	124	62	9	--	11.84	
8	81	48	129	65	10	2	11.76	
9	67	40	107	54	4	--	11.72	
10	71	41	112	56	5	--	11.67	
11	70	45	115	58	6	8	11.69	
12	77	55	132	66	11	--	11.58	
13	65	50	115	58	6	--	11.52	
14	67	43	110	55	5	--	11.47	
15	70	36	106	53	4	--	11.43	
16	76	46	122	61	8	--	11.35	
17	78	58	136	68	13	--	11.22	
18	79	63	142	71	15	2	11.09	
19	86	61	147	74	18	--	10.91	
20	86	62	148	74	18	--	10.73	
21	89	63	152	76	20	--	10.53	
22	88	66	154	77	21	3	10.35	
23	87	63	150	75	19	--	10.16	
24	86	60	146	73	17	--	9.99	
25	89	60	149	75	19	--	9.80	
26	87	60	147	74	18	--	9.62	
27	89	63	152	76	20	--	9.42	
28	88	60	148	74	18	--	9.24	
29	89	62	151	76	20	--	9.04	
30	87	63	150	75	19	--	8.85	

Figure 9.--Numbers in column 5 are numbers in column 4 divided by 2. ET and rain are recorded in hundredths inches to avoid possible errors resulting from misplaced decimal points. ET values are obtained from table 1. Twelve inches of soil moisture were assumed to be available on the first day of the sample month.

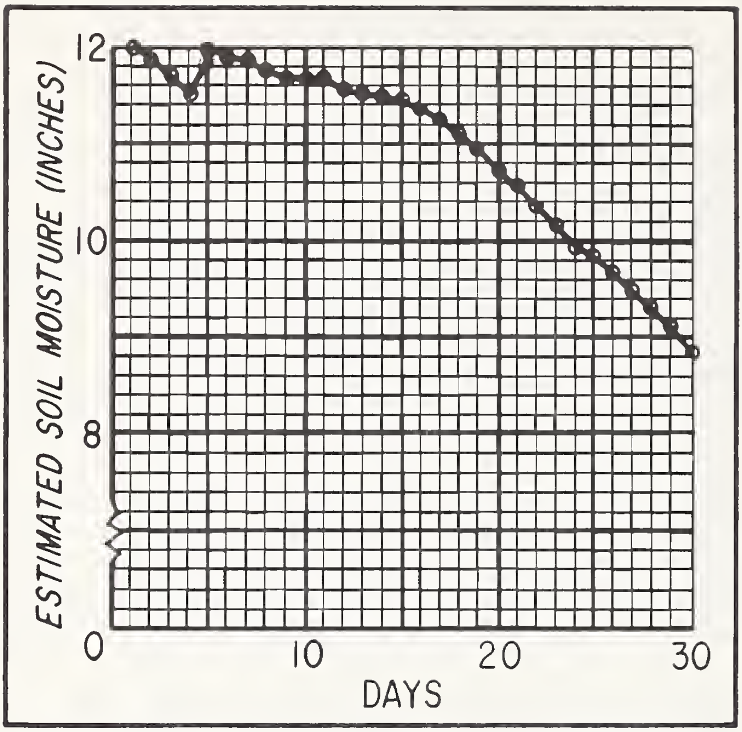

Figure 10.--Graph of estimated soil moisture, from column 8, figure 9.

Certainly much more work is needed to develop methods for estimating soil moisture depletion in forest stands and to determine what different degrees of depletion mean in terms of fire control. Such work is planned by the Southeastern Forest Experiment Station. In the meantime the writer will welcome letters or communications giving results of field trials; also opinions on the success or inadequacy of this tentative method.

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